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13. ABSTRACT (Maximum 200 words)

In this program sponsored by the ARO Physics office we have made significant progress in designing, constructing and using a novel device called the Near-field Scanning Optical Microscope, or NSOM. The microscope is one of a family of instruments which use either small apertures or finely sharpened probes to scan the surface of a sample and thereby construct an image of that surface. Since demonstrating the utility of the microscope of our design, we have subsequently built a number of other NSOMs incorporating a variety of illumination modes and signal transduction methods in imaging surfaces and taking optical spectra of features on these surfaces. Theoretical efforts to model the optical throughput of the probe have been undertaken, and the initial results have been published. The program has supported several students, including a student who, after graduation, designed the first commercial NSOM instrument.

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"Development of an Analytical Photon Scanning Tunneling Microscope"

FINAL REPORT

Michael Paesler

May 9, 1994

U. S. ARMY RESEARCH OFFICE

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Investigations in near-field optics in our laboratory have included both experimental and theoretical research. The thrust of our program centers on two aims: understanding and developing near-field imaging. In particular we are studying and developing the near-field scanning optical microscope (NSOM). In previous reports we have dealt somewhat with progress in instrument development on fronts removed from optical concerns (e. g. force feed-back profiling, image processing, piezoelectric control, and vibration isolation). These aspects of our NSOM research are now quite mature and our concern now lies principally with the optics of near-field imaging. Thus this progress report deals almost exclusively with the NSOM optics and in particular with the tapered optical fiber which lies at the heart of an NSOM and at which the super-resolution optical signal is transduced.

The transduction of high spatial frequency information in an NSOM takes place in the near-field region very close to the object being imaged. As a tip is scanned over the object, a convolution of the object and tip results in a carrying of high spatial frequency information by low frequency propagating modes. This high resolution information is evanescent in the absence of the probe, but the presence of the tip allows the information to "tunnel" to the far field via the overlap in the tip-object interaction. Large optical field gradients at the end of the probe thus enable super-resolution, and our interest is theoretically determining the best manner to create substantial gradients (for increased resolution) at high intensities (for increased signal).

The creation of large field gradients can be realized trough the creation of a small aperture in an "opaque" coating at the tip of a tapered optical fiber. Our analysis of the modal structure of such tapered probes [1] clearly demonstrates how such a structure delivers the high frequency information used in imaging in near-field microscopy, and we have demonstrated successful use of our probes in several different NSOM configuration [2,3]. We make this structure by coating the edge of the taper with aluminum to a few skin depths, leaving a small (50 nm) opening at the apex. In the optical regime this result is an aperture that is somewhat "muddy" on these scales since the skin depth is on the order of the aperture diameter. Nevertheless, this technique is well established and quite generally used, and theoretical work has shown that the field at the apex of such a tip is quite confined [1].

While the general shape of an NSOM taper is well known, it is not clear just what the optical morphology for light delivery should be. Indeed, when milliwatts of power are incident in the fiber in an illumination-mode

instrument, nanowatts of power emerge from the aperture. Simple thermodynamic analysis shows the most of this power is lost before the near-field region is reached, i. e. when the fiber diameter is still larger than the wavelength of the incident radiation. We have analyzed the optics of the light transmission through a fiber [4] in efforts to determine the light-loss mechanisms. Our analysis based on an extended-zone scheme for a conical taper suggests that multiple reflections of increasing density cause appreciable losses in the coating walls, and led us to consider the tip fabrication process [5,6] and to question how one might fabricate alternative and more efficient geometries [7].

In a demonstration of imaging in the reflection mode, graduating student Patrick Moyer incorporated much of what we have learned in the development of the instrument to gather data for his Ph. D. thesis. A subject of his thesis results [8] was the first demonstration of reflection mode near-field imaging employing shear-force feedback. (Upon graduation in May of 1993, Dr. Moyer joined TopoMetrix corporation where he has commercialized the first NSOM. The TopoMetrix *Aurora* instrument is based on the designs he developed for his thesis and is already being marketed).

Graduate student Andres LaRosa has devised a scheme to use time as a contrast mechanism in an NSOM [9]. Single crystal silicon wafers are imaged in the infrared using a HeNe laser while the wafer is simultaneously pulsed with visible radiation. By studying the time dependence of the infrared transmittance, defect distribution on the nanometer scale can be imaged, and sample nanostructure can be studied. First results indicating successful realization of this imaging mode were presented at the Second International Conference on Near-Field Optics (NFO-2) held in Raleigh in August of 1993 and hosted by us.

While our work has remained clearly focused on theoretically understanding and experimentally developing near-field imaging, our specific aims have changed somewhat from our initial proposal. As we have understood more about imaging modalities, for example, it has become clear that our initial suggestion of using only evanescently-illuminated samples was neither necessary nor advised. Superior resolution can be obtained through use of samples viewed in the illumination mode using the aperture-carrying probe. This has led us to consider tip morphology and signal transduction in more detail. Our students have resulted in a determination not only of an improvement manner to achieve high-performance tapers, it has -perhaps more importantly-suggested that other geometries more exotic than a simple conic taper might be preferred in NSOM operations. We are

further studying both the morphology which will give the best optical performance as well as the means of obtaining such a shape. Our close work with Sutter instruments (whose instruments are used in the majority of the laboratories engaged in near-field research) and TopoMetrix (which is the first company to commercialize the NSOM) has contributed in bringing the NSOM technology to bear on a number of practical applications.

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